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Lockheed Aircraft Corporation

ADVANCED DEVELOPMENT PROJECTS
BURBANK, CALIFORNIA

REPORT NO. SP-665
DATE 5-14-64
COPY NO. #6

MODEL A-12

TITLE LIGHTNING TESTS - MODEL A-12 PLASTIC RUDDER

STATINTL

PREPARED BY [redacted]

REVIEWED BY

APPROVED BY

Advanced Development Projects

REVISIONS

DATE	PAGES AFFECTED

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ABSTRACT

This report presents the results of lightning tests conducted on a Model A-12 airplane plastic rudder. The tests demonstrate that a simple segmented foil outside of the dielectric material provided adequate protection for almost any stroke energy level which might be encountered.

ACKNOWLEDGEMENT

The authors wish to acknowledge with appreciation the extra effort and spirit of cooperation of Messers.

STATINTL [redacted]

STATINTL [redacted] in the performance of these lightning tests.

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OBJECT

To observe the effects of lightning strikes on the plastic rudder of a Model A-12 airplane. In addition, propose a practical means of enabling the rudder to sustain these lightning strikes with no/minimum damage.

CONCLUSIONS

It appears that the use of segmented foil mounted on the outside surface of the dielectric materials provides adequate protection for any stroke energy level that may be encountered. This was demonstrated in the second series of tests. The segmented foil type of arc shunt should be relatively easy to install and maintain. It should not compromise aircraft performance and need not appreciably degrade the performance of electronic equipment.

RECOMMENDATIONS

All exposed dielectric parts of the airplane should be considered as candidates for severe damage from lightning strikes. An estimate of their stroke termination probability should be attempted. Parts of the airplane that should be considered for protection are: Isolated nose sections (H.F. antenna exciter), nose radomes, plastic engine spikes, plastic fins, and possibly, plastic wing tip parts.

The arc shunts in each case should be approximately like those which were evaluated in the second series of tests. Detailed dimensions are not

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RECOMMENDATIONS (Continued)

critical; however, radical changes in size and/or spacing may need to be tested.

The arc shunt material must be as exposed to ambient air as is possible. A light coat (.001 inch) over the foil is permissible, but in no case can a thick coating of any dielectric material be used. The foil segments must be cemented to the outer surface; metallic fasteners of any sort must be avoided.

TEST SPECIMEN

The test article consisted of a complete rudder assembly (Serial No. 6) which had been subjected to structural tests at room and elevated temperatures, as well as room temperature internal pressure tests (see ADP Report SP-398). After the foregoing tests, the rudder was returned to the contractor for clean-up and retreatment of the surfaces to duplicate flight article requirements.

Prior to shipment to the test activity, STATINTL [redacted] STATINTL [redacted] an inspection was made to locate and record areas of existing damage. Inspection of the left hand side (ref. Photo 1) revealed the following:

1. Areas 1, 2, 10, 11 and 12: Unbonded from core and substructure. The exact condition was not discernable.
2. Area 3: Delamination of skin.
3. Area 4: Scab on doubler apparently unbonded.

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TEST SPECIMEN (Continued)

4. Area 5: Unbonded.

5. Areas 6, 7, 8 and 9: Heads of jo-bolts pulled out of substructure.

Inspection of the right hand side (ref. Photo 2) revealed the following:

1. Areas 1, 2 and 3: Unbonded from core and substructure. The exact condition was not discernable.

2. Area 4: Delamination of skin.

3. Areas 5 and 6: Scab on doubler apparently unbonded.

TEST SET-UP AND PROCEDURE

The test article was mounted on a rudder post supported on a stub fin removed from the static test article. The gudgeon arm and actuator link were connected to the rudder. Except for the stand to support the stub fin, the rudder duplicated installation on a flight article.

Two series of tests were made, the first on 11 April 1964 and the second on the 25th of April 1964. The first series of lightning tests ran to a maximum intensity of approximately five million volts at thirty thousand eight hundred amperes. The second series of tests utilized higher currents (maximum of about 200,000 amperes) at lower voltages (approximately 150,000 volts).

In the first series of tests the discharge electrode was approximately twelve feet above the rudder. Three basic chordwise locations were used; aft, center, and forward. In the aft position the electrode was above the tip trailing edge portion of the rudder. The center position had the electrode approximately midway between the tip leading and trailing edges. The

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TEST SET-UP AND PROCEDURE (Continued)

forward location had the electrode above the most forward edge of the stub fin and still about twelve feet above the rudder tip.

Included in the first series of tests were some side shots. The electrode about seven feet above the floor and approximately eight feet from the rudder plane. Two chordwise positions were used. In the forward position, the electrode was located midway between the post and leading edge areas. In the aft position, the electrode was located midway between the post and the trailing edge areas.

In the second series of tests two basic electrode positions, forward and aft, were used. In each position the electrode was placed approximately 1/4 inch away from either the rudder tip leading or trailing edge.

For the high current tests, local portions of the leading edge were used.

TEST RESULTS

Test results are summarized in Tables I and II and in photographs of the various test runs.

STATINTL

STATINTL Based on these results of the tests conducted at the [redacted] it appears that lightning damage to vulnerable components may be prevented quite easily if proper protection is provided.

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TABLE I SUMMARY OF TEST RESULTS (FIRST SERIES)

RUN NO.	BOLT INTENSITY		O.H. ELEC. POSIT		HIT LOCAT TIP		REMARKS
	KILOVOLTS	KILOAMPS	FWD	AFT	FWD	AFT	
A	3060	113		✓		✓	TRIAL RUN. GROUNDING WIRE ON PERIPHERY OF RUDDER.
I	〃	〃		〃		〃	SAME AS "A"
II							SAME AS "A"
III							GROUNDING WIRE REMOVED. ARC TRAVELLED INTERNALLY TO GROUND.
IV							SAME AS III
V				↓		↓	RUDDER T.E. DEFL LEFT RESULTS SAME AS III
VI				✓		✓	T.E. DEFL LEFT. RESCON TAPED ON TIP T.E. ARC PUNCTURED RESCON AND TRAVELLED INTERNALLY TO GROUND.
VII			CENTERED		✓		NEW RESCON PUT ON TIP L.E. AND T.E. SAME RESULT AS VI
VIII		↓		↑	〃		ALUMINUM FOIL USED IN PLACE OF RESCON. ARC TRAVELLED INTERNALLY TO GROUND.
IX		.113					L.E. AND T.E. FOILS INTERCONNECTED WITH COPPER WIRE WHICH WAS GROUNDED TO AFT SEMI-CONDUCTOR STRIP.
							PHOTOS SHOW LIGHT STREAMERS FROM WIRE OTHERWISE NO CHANGE IN RESULTS.
X		NO RDG	CENTERED				REMOVED ALUMINUM FOIL FROM TIP L.E. AND T.E. COPPER WIRE RAN FROM VERTICAL SEMI-CONDUCTOR STRIP
		↑			↓		TO WITHIN ONE FOOT OF L.E ON TIP OF RUDDER EXCEPT FOR CLEARER STREAMER DEFINITION, RESULTS SAME.
XI					✓		ALUMINUM FOIL CORNERS INSTALLED COPPER WIRE FROM X RETAINED. ARC TRAVELLED INTERNALLY.
XII			SIDE		TOP POST AREA		SIDE SHOT ELECTRODE 83 INCHES FROM FLOOR AND 3 FEET FROM MID-CHORD OF RUDDER. ARC APPEARED
							TO STRIKE RUDDER SLIGHTLY ABOVE AND AFT OF POST. WIRE AND FOIL SAME AS X
XIII				SIDE		✓	ARC STRUCK TIP T.E. AND APPEARED TO TRAVEL DOWN T.E. BEFORE DISAPPEARING INTERNALLY.
XIV				SIDE		✓	1 INCH LONG COPPER WIRES AT 1½ INCH WERE TAPED AROUND PERIPHERY OF RUDDER. COPPER WIRE
							INTERCONNECTING L.E. AND T.E. STRIPS TAPED ALONG BOTTOM OF RUDDER. SLIGHT GLOW AT ENDS OF
							WIRES WHEN STRUCK BY ARC. SUBSEQUENT TEST RUN WITH COPPER "NEEDLES."
XV			SIDE		✓		ARC STRUCK TOP OF RUDDER INSTEAD OF POST AREA. FAINT GLOW AT ENDS OF SOME "NEEDLES"
XVI		↓	✓		✓		PHOTOS REVEALED SLIGHT GLOW AT ENDS OF "NEEDLES" ALONG TOP AND L.E. OF RUDDER
XVII			CENTERED		✓		SAME AS XVI
XVIII		NO RDG		✓		✓	SAME AS XVI EXCEPT GLOW ALONG T.E.
XIX A		.494		✓		✓	GLOW ALONG T.E. AND TOP
XIX B		.494		✓		✓	NO GLOW. MISSING "NEEDLES" ON TOP WERE REPLACED.
XIX C		.494		✓		✓	SAME AS XIX A.
XX		.494	✓		✓		PHOTOS SHOW ARC TRAVELLING ALONG L.E.
XXI		3.10	✓		✓		SAME AS XX SIGNS OF SCORCHING IN GAP BETWEEN "NEEDLES". DISCOLORATION EASILY REMOVED WITH PENCIL
							ERASER. LOOSE NEEDLES RETAPED
XXII	↓	3.10		✓		✓	SAME AS XXI
XXIII	3060	21.80		✓		✓	SAME AS XXI NO VISIBLE DAMAGE. ODOR DETECTED. EVIDENCE OF BURNING OF TIP AT ENDS OF NEEDLES.
							LOOSE AND MISSING NEEDLES REPLACED.
XXIV	4386	30.8	✓		✓		PRIMARY PATH OF ARC ALONG L.E.
XXV	↕	↕		✓		✓	ARC TRAVELLED AROUND RUDDER SLIGHT SCORCHING ON TOP SURFACE AT ENDS OF NEEDLES.
XXVI				✓		✓	RUDDER T.E. DEFLECTED LEFT. RESULTS SAME AS XXV.
XXVI A	4386	30.8		✓		✓	RESULTS SAME AS XXVI
XXVII	2193	15.7		✓		✓	REMOVED NEEDLES FOR REMAINING TESTS. TIP T.E. OPENED BY ARC. TRACKING ON TOP.
XXVIII	4386	30.8	✓		✓		TRACKING ON TOP FORWARD.
XXIX	4386	30.8	✓		✓		RERUN SAME RESULTS.
XXX	4386	30.8		✓		✓	½ IN. DIA PATCH BLOWN OFF SOME SMOKE FROM PATCH AREA. SLIGHT TRACKING RUDDER ROTATES FREELY.
XXXI	4386	30.8		✓	STUB FIN T.E.		RUDDER AREA AROUND STUB FIN T.E. AND TOP OF RUDDER T.E. HARD TO DETECT DISCOLORATION.

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RUN NO	BOLT INTENSITY KILOVOLTS	BOLT INTENSITY KILOAMPS	HIT LOCATION FWD	HIT LOCATION AFT	REMARKS
1	129	6.0		TIP	ALUMINUM FOIL TAPE 1 INCH WIDE 3 MILS THICK PLACED ON TIP EDGE, VERT. ST. JUST FWD OF REAR SEMI-CONDUCTOR STRIP,
	↓			↓	AND 2 INCHES AFT OF L.E. 1/8 INCH GAPS AT 1½ INCH C-C. SOLID STRIP ALONG BOTTOM CLOSING RIB. ARC WENT
					INTERNALLY AND LOOSENED TIP ATTACHMENT AT APPROX .30 C.
2	↓	22			THE GAPS ON THE ALUMINUM FOIL VERT. STRIP WERE REDUCED TO 1/8 INCH FOR ABOUT 18 INCHES AND AFT ALONG THE TIP.
					HIPOT WIRE ATTACHED TO LOCAL TEST AREA TO CHECK GAP EFFECT. PHOTOS SHOW 1/8 INCH GAP SPACING MORE EFFECTIVE
3	↓	18			ALL FOIL GAPS CHANGED TO 1/8 INCH. WIRE IN PLACE OF TAPE ALONG BOTTOM CLOSING RIB. ARC TRAVELLED AROUND RUDDER
4	↓	18		↓	REPEAT OF 3 WITH SAME RESULTS
5	↓	30		↓	INCREASE IN CURRENT. SAME RESULTS AS 4.
6	↓	30		↓	ATTEMPT INCREASE IN CURRENT. SAME DISCHARGE PATTERN AS 4.
6A	↓	24		↓	RERUN OF 6. SLIGHT SEPARATION OF TIP FAIRING FROM TIP RIB AT .30 CHORD STA. GAPS BETWEEN TAPES ABOUT ... INCH
					TAPES REPLACED MAINTAINING 1/8 INCH GAP IN SPACING.
6B	↓	24		↓	RERUN RESULTS SAME AS 6 EDGES MELTED IN SOME TAPES. WORN TAPES REPLACED
7	↓	37		TIP	ATTEMPT INCREASE IN CURRENT RESULTS SAME AS 6B
8	↓	86	TIP	↓	MAIN ARC ALONG L.E. SOME TAPES VAPORIZED
9	↓	66	TIP	↓	L.E. TAPES REMOVED. PORTION OF L.E BLOWN OFF. RUDDER L.E SEPARATION
10	↓	46	↓	TIP	ARC TRAVELLED FORWARD ALONG TOP. FURTHER SEPARATION OF L.E
11	↓	72	↓	TIP	TAPE FORWARD OF VERT STRIP WAS REMOVED ARC TRAVELLED DOWN VERT. STRIP SOME TAPES VAPORIZED
12	129	30	↓	TIP	VERT TAPE STRIP REMOVED. ARC WENT INSIDE. SEPARATED T.E. BLEW OFF FWD. AND AFT PORTION OF TIP FAIRING. BLEW OUT
					A 30 BOLT ALONG F.S. 109 ALMOST DIRECTLY ABOVE PO
13	150	160	LWR L.E.		RUDDER ROTATED SO THAT L.E SECTION IS ADJACENT FIRING. CHANGES IN ATTEMPT TO INCREASE AMPERAGE OF ARC.
					TEST SECTION EXTENDS TWO FEET ALONG L.E. AND 1 FOOT ALONG CLOSING RIB. TAPE VAPORIZED BUT NO DAMAGE
14	150	202	LWR L.E		TAPE REPLACED ALONG L.E. TEST SECTION OF APPROX 20 INCHES TAPES VAPORIZED BUT NO DAMAGE
15	150	151	LWR L.E		SURFACE CLEANED, ALL TAPE REMOVED. SAME TEST SECTION L.E. TEST SECTION VIRTUALLY VAPORIZED BY BLAST

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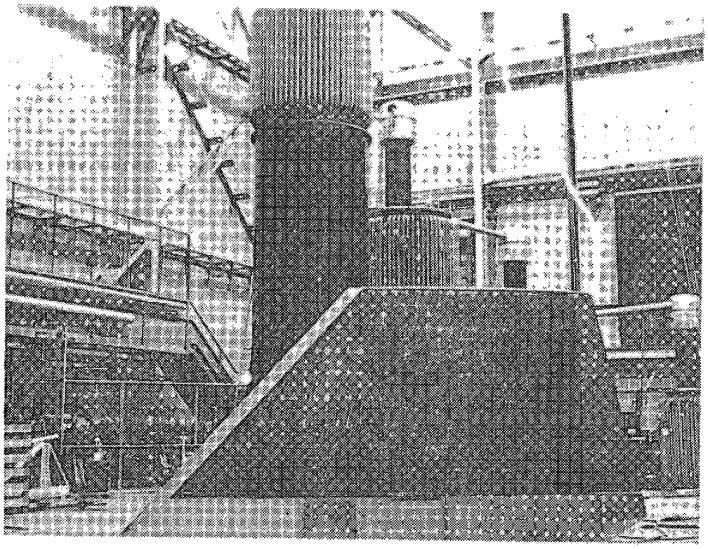

Photo A-1 Trial run with copper grounding wire around periphery of rudder.

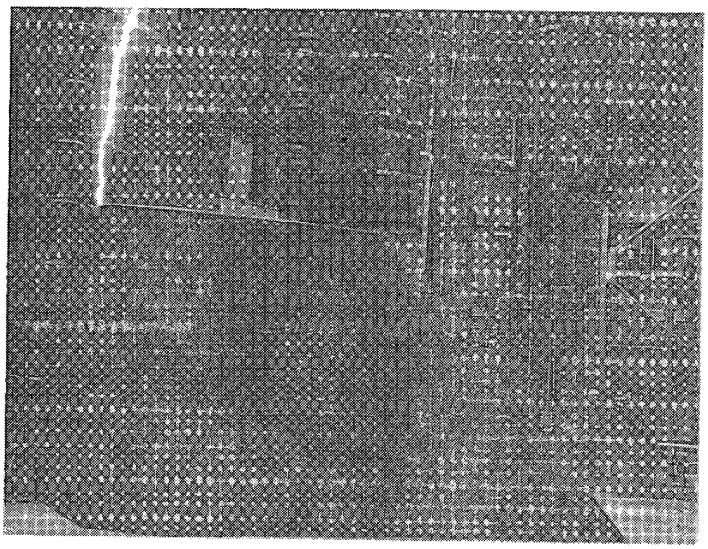

Photo I-1 R.H. side of rudder at second trial run with copper grounding wire around periphery of rudder.

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Photo II-1 Run II Test or sample run with copper grounding wire around periphery of rudder.

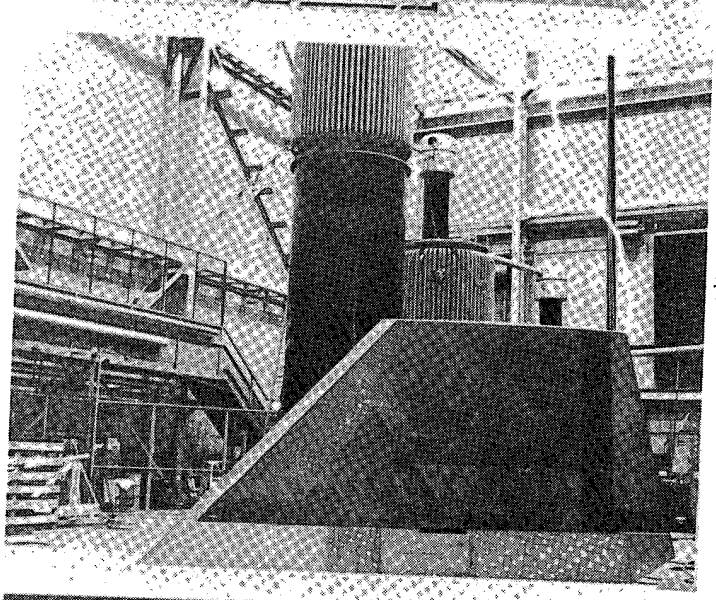

Photo II-2 L.H. side during trial run.

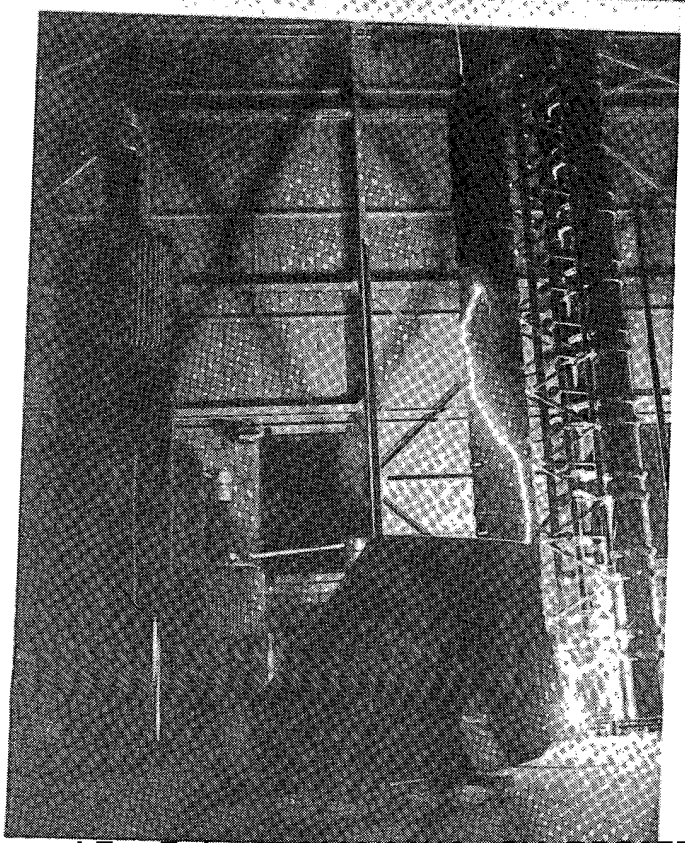

Photo II-3 Trial run. Note location of electrode.

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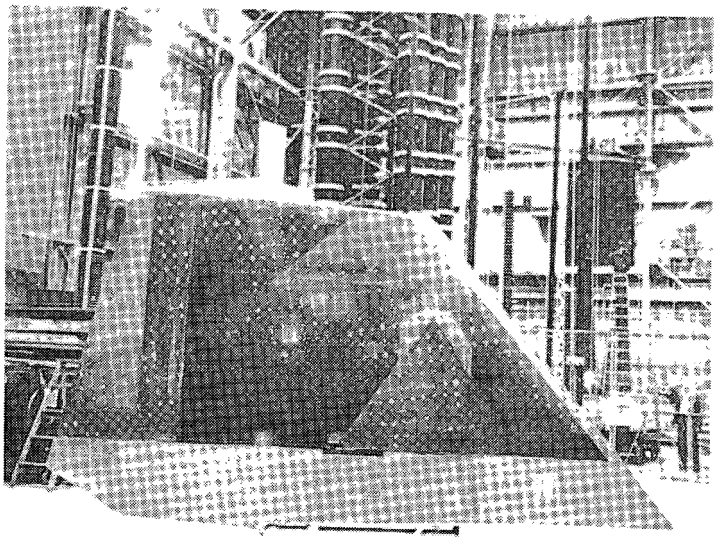

Photo III-1 Run III with copper grounding wire removed. Note that arc has entered rudder and followed an internal path to ground.

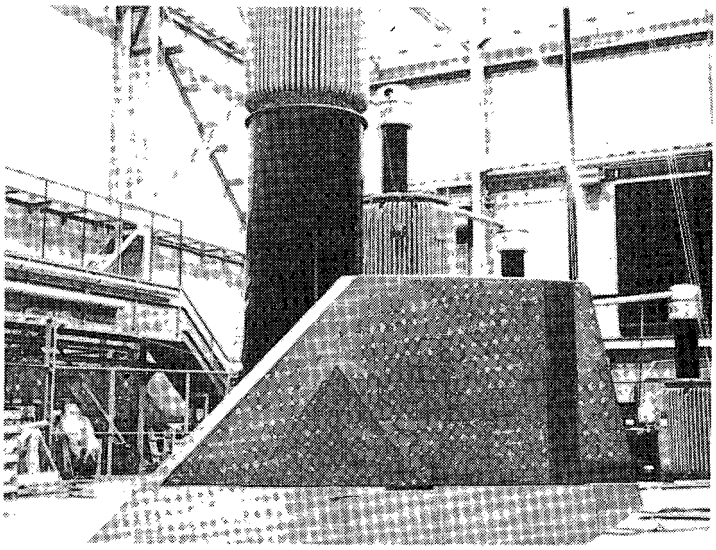

Photo III-2 Run III L.H. side.

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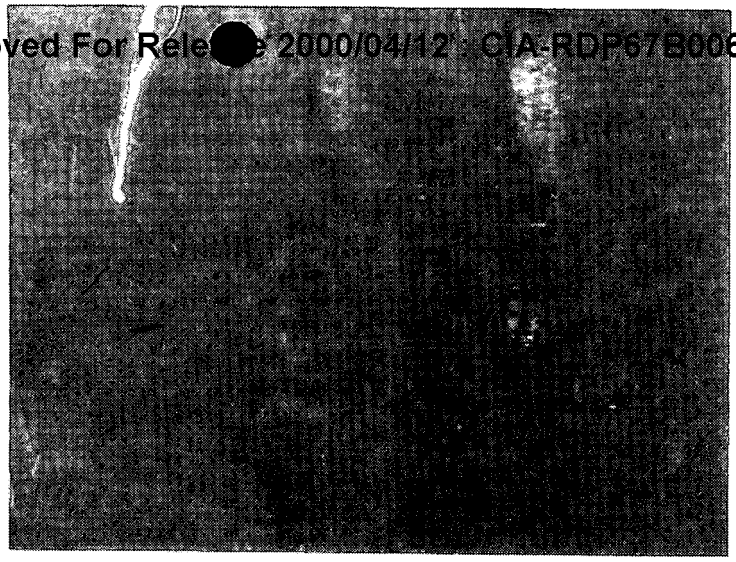

Photo IV-I Run IV with copper grounding wire removed. R.H. view.

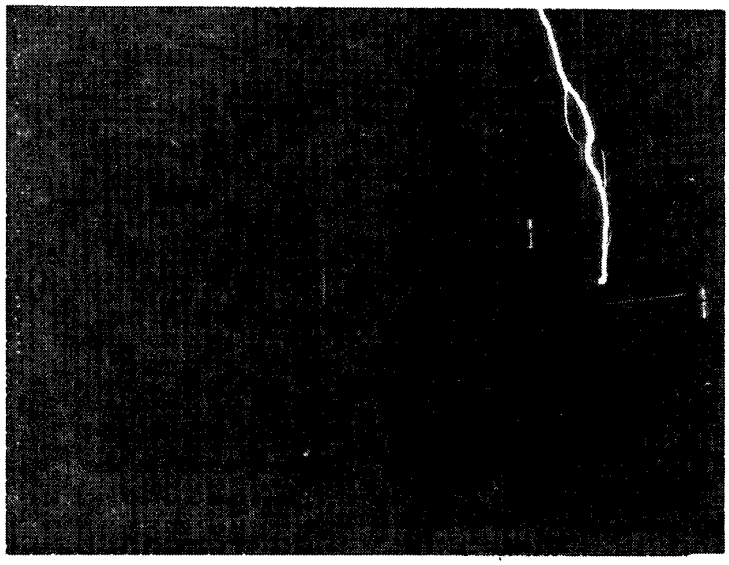

Photo IV-2 Same as above except L.H. side.

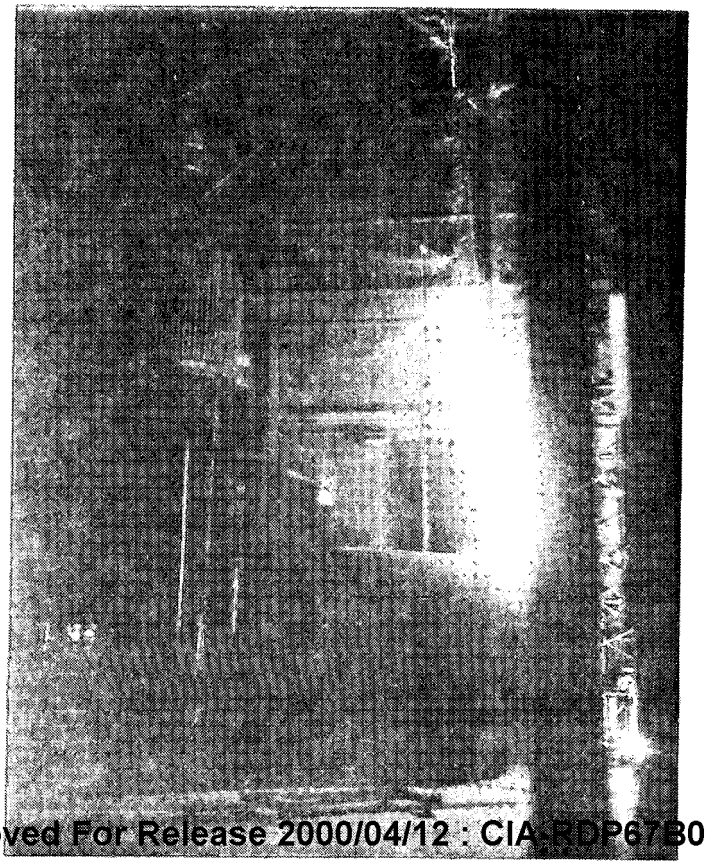

Photo IV-3 Run IV is similar to Run III. Again arc moves along an internal path to ground which could mean potential damage.

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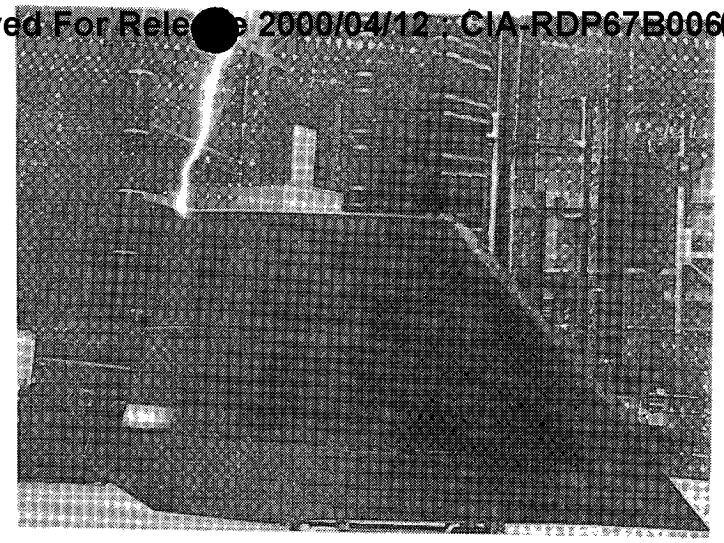

Photo V-1 Run V-Rudder Deflected T.E. Left.

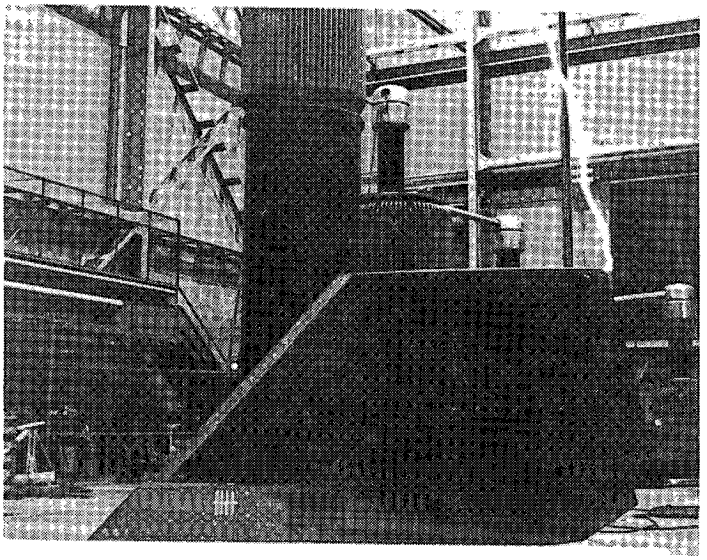

Photo V-2 Run V Results are similar to Runs III and IV.

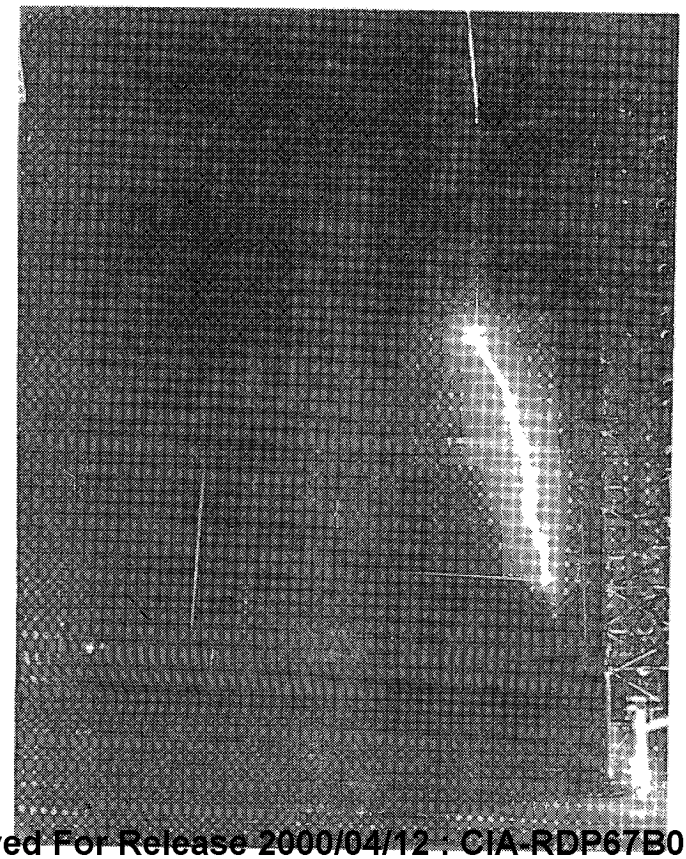

Photo V-3.

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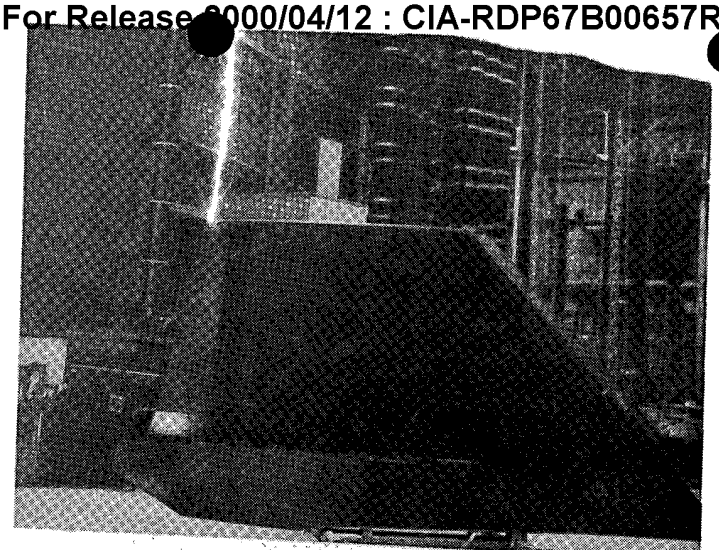

Photo VI-1. Run VI Small Piece of Rescon on T.E. corner. Rudder deflected.

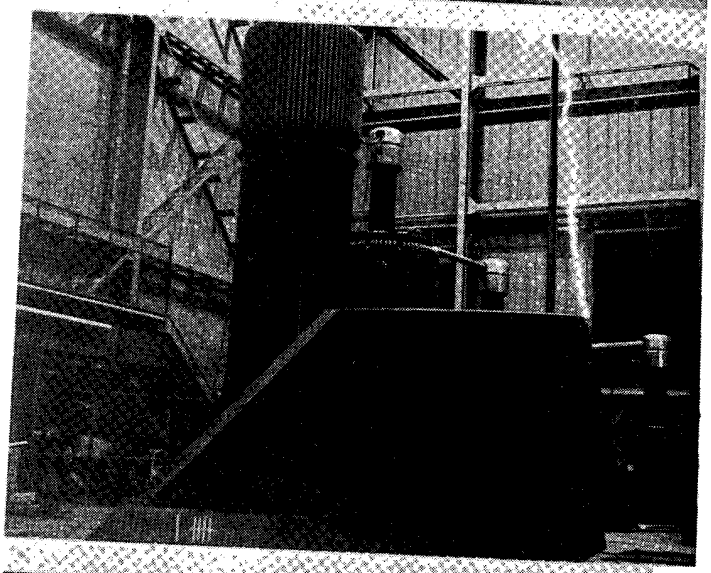

Photo VI-2. Note small glow down along T.E. Arc seems to be entering rudder along T.E.

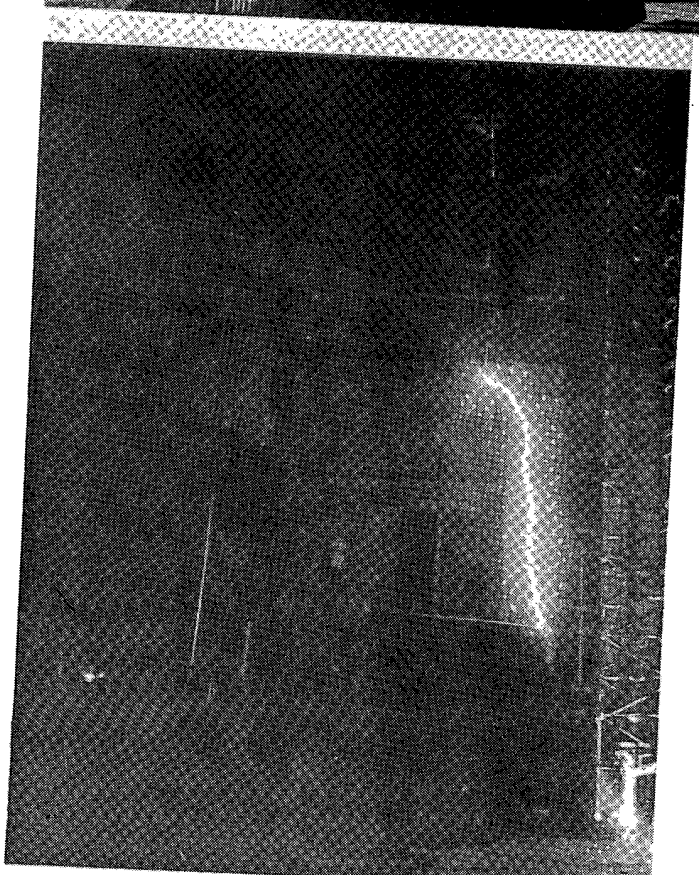

Photo VI-3. Run VI. Examination after run revealed small puncture through Rescon.

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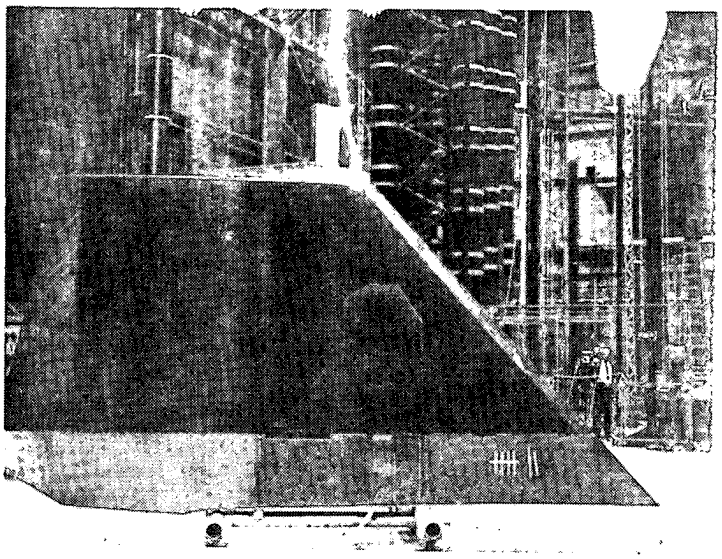

Photo VII-1. Run VII. Electrode in Center Position. Rescon on Rudder Tip Corners.

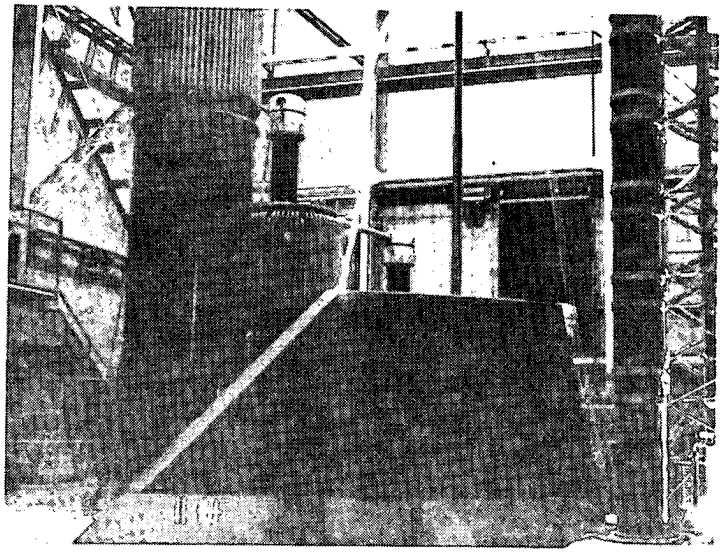

Photo VII-2. Run VII. L.H. Side

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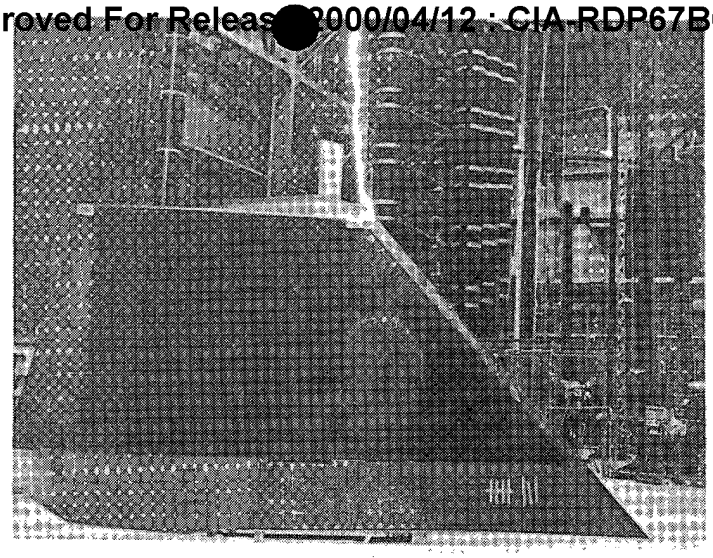

Photo VIII-1. Run VIII. Aluminum Foil Installed L.E. and T.E. Electrode in center position.

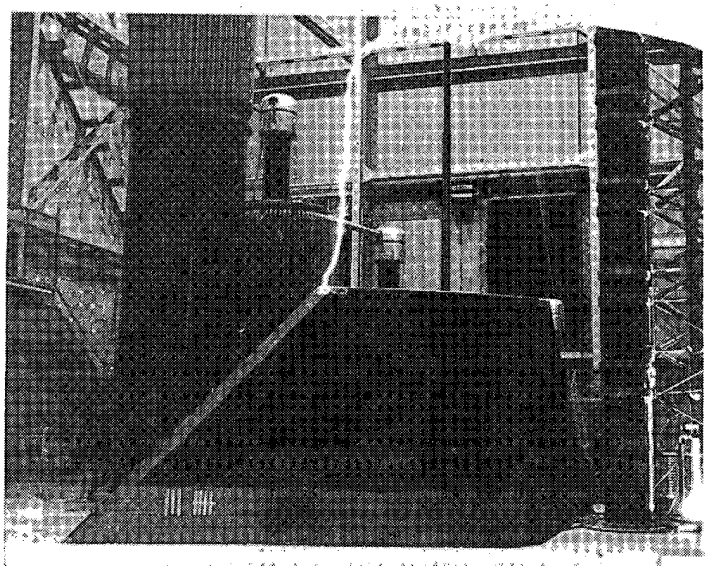

Photo VIII-2.

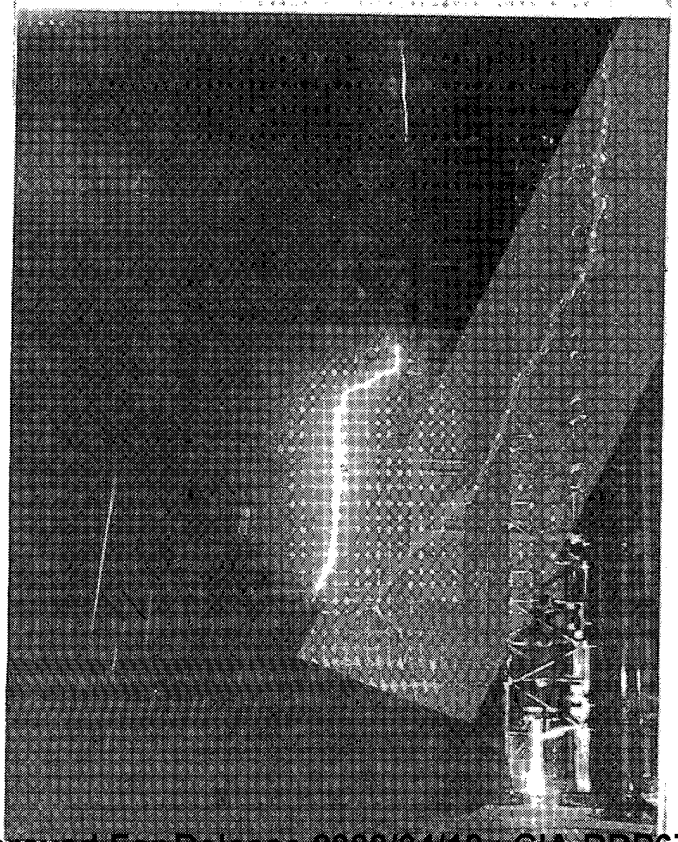

Photo VIII-3.

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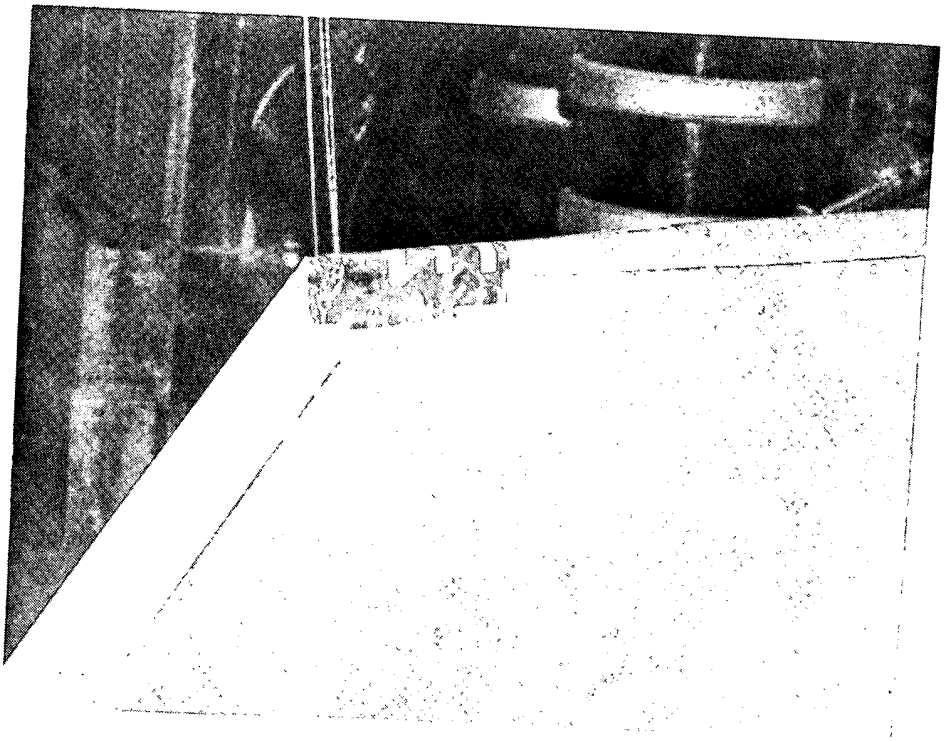

Photo VIII-4. Aluminum Foil on L.E. Rudder Tip as Tried in Run No. VIII.

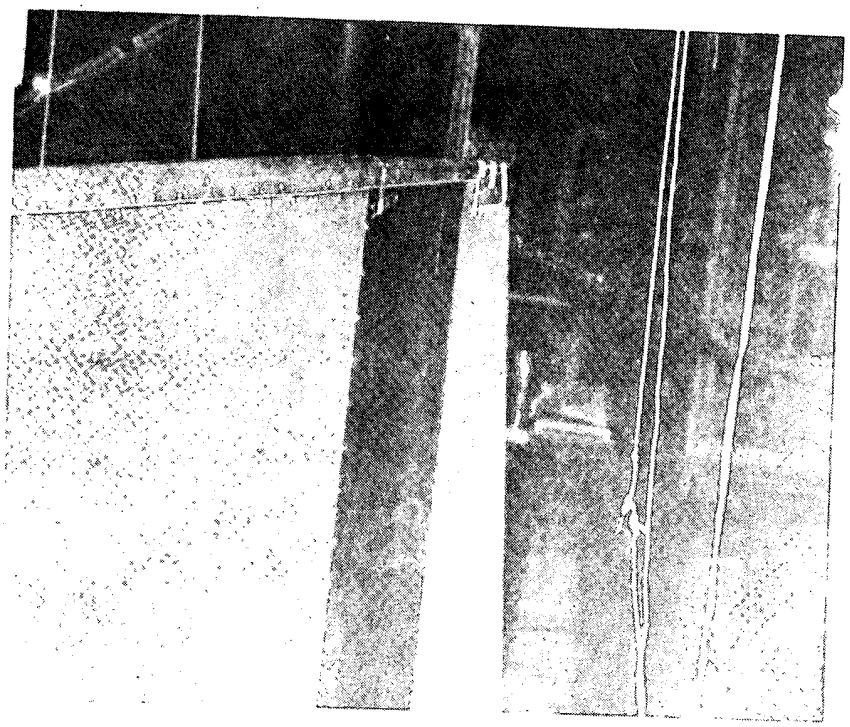

Photo VIII-5. Aluminum Foil on T.E. Rudder Tip as Tried in Run No. VIII.

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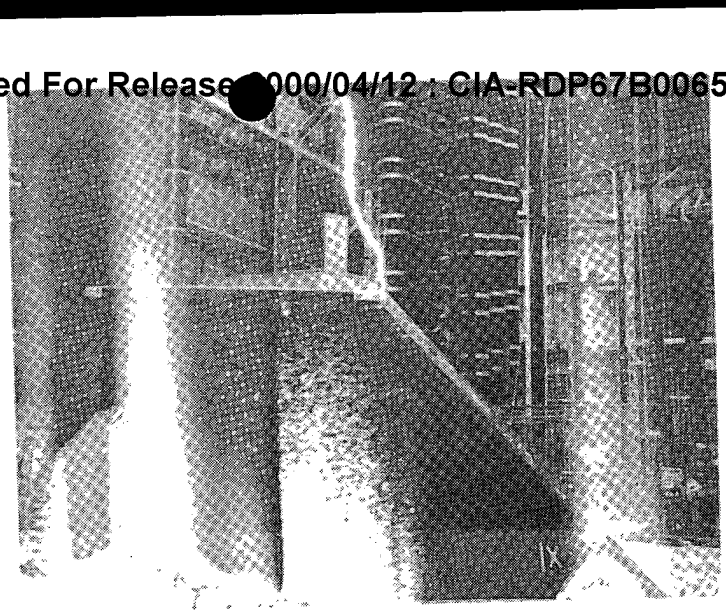

Photo IX-1. Run IX Aluminum Foil plus Copper Wire on Trip. Electrode in Center Position.

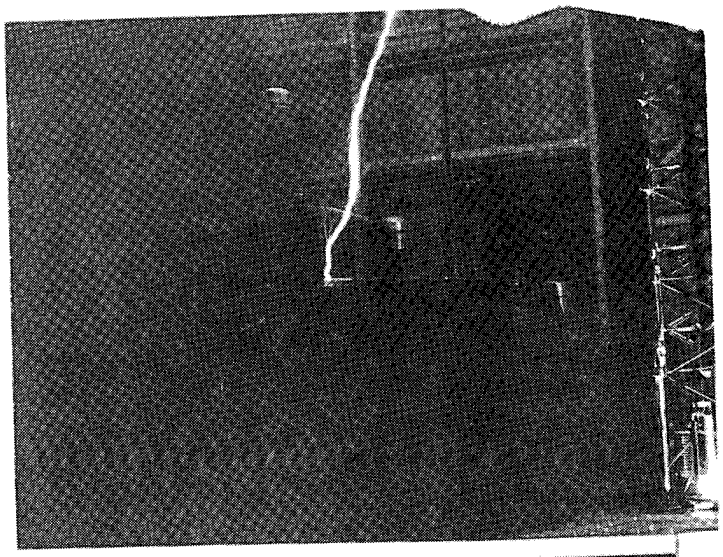

Photo IX-2.

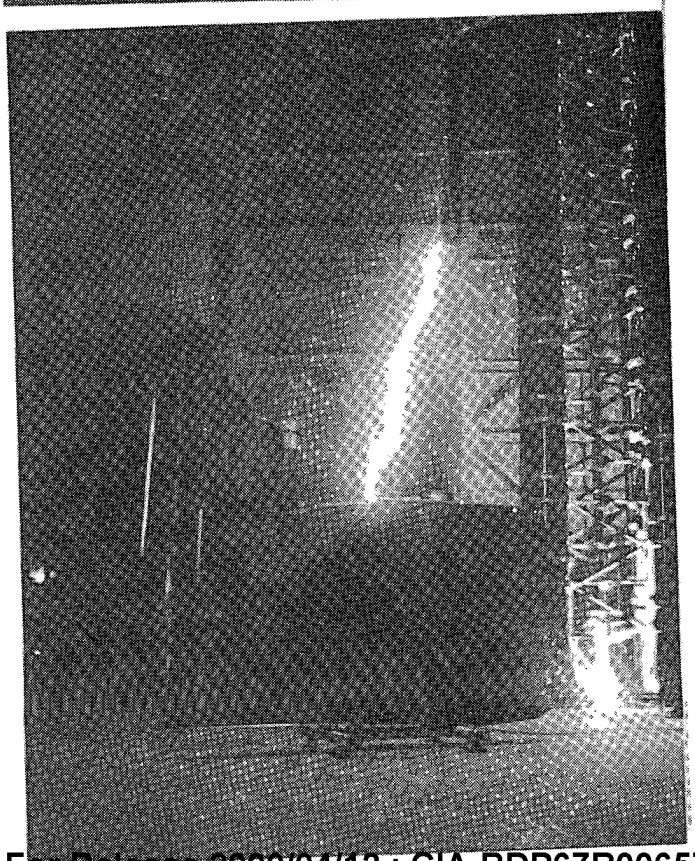

Photo IX-3. Note trace of streamers at top of rudder.

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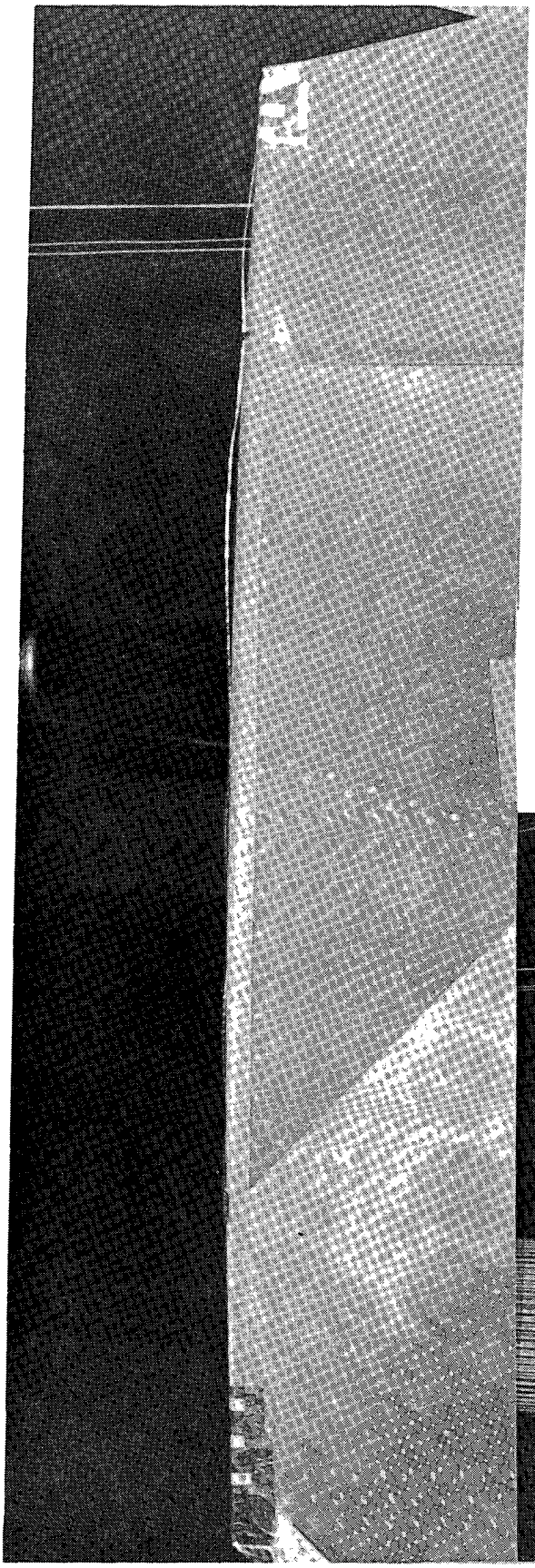

Photo IX-4. Enlargement of Photo IX-5.

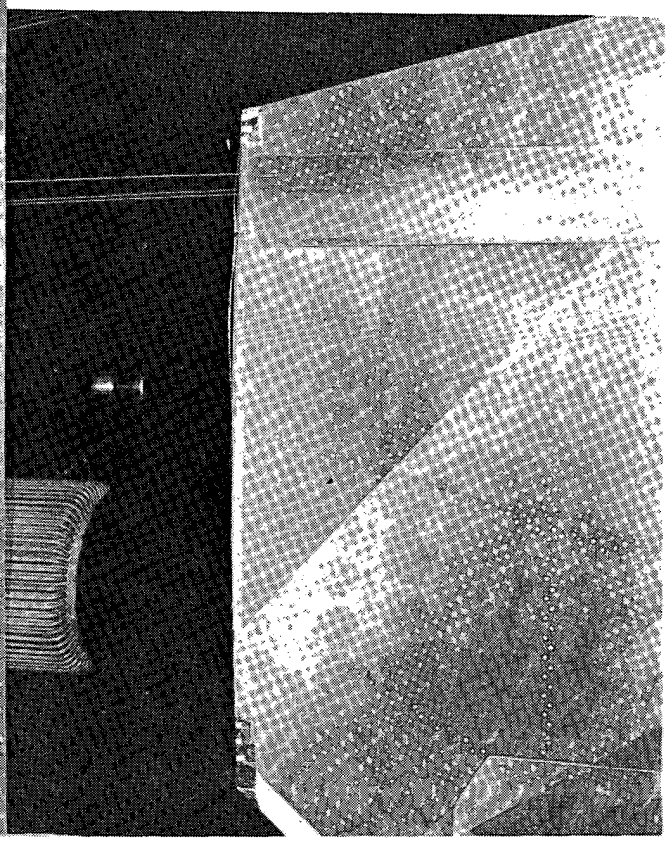

Photo IX-5. Aluminum Foil on Rudder Tip L.E. and T.E. Connected with Copper Wire for Run IX. Copper wire was also connected to surface treated connecting band.

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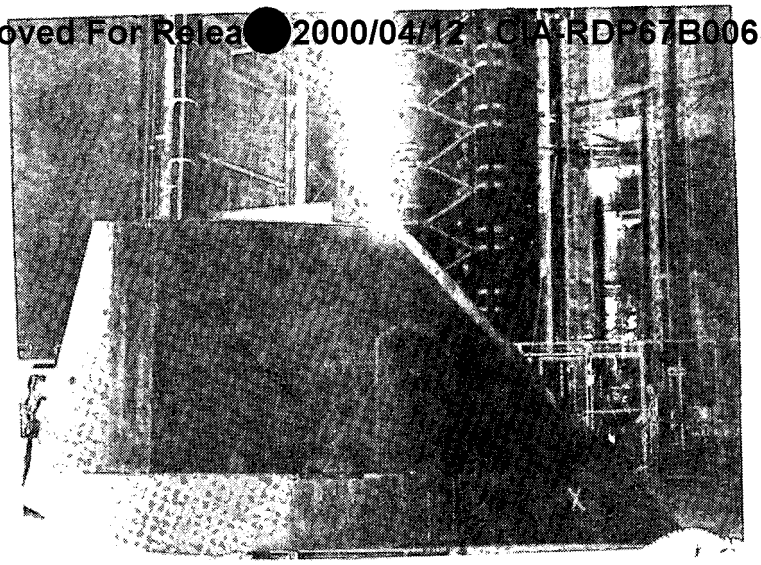

Photo X-1. Run X. Aluminum Foil Removed. Short copper load on tip. Note streamers along top of rudder.

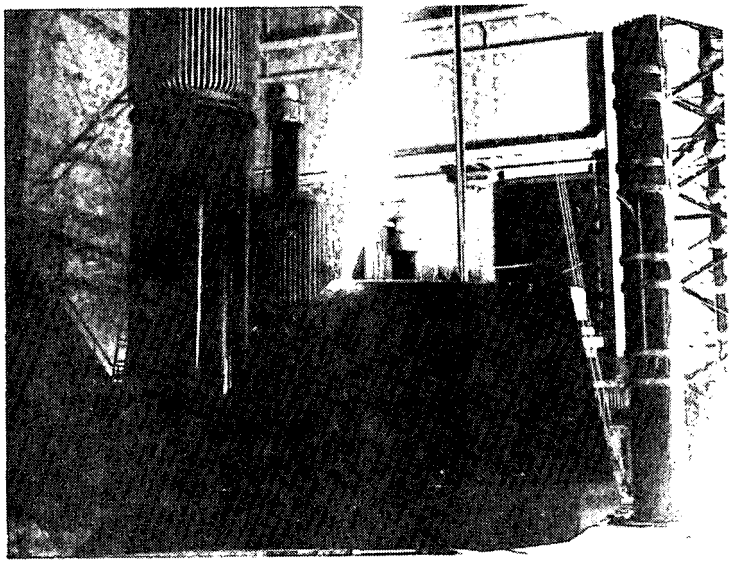

Photo X-2.

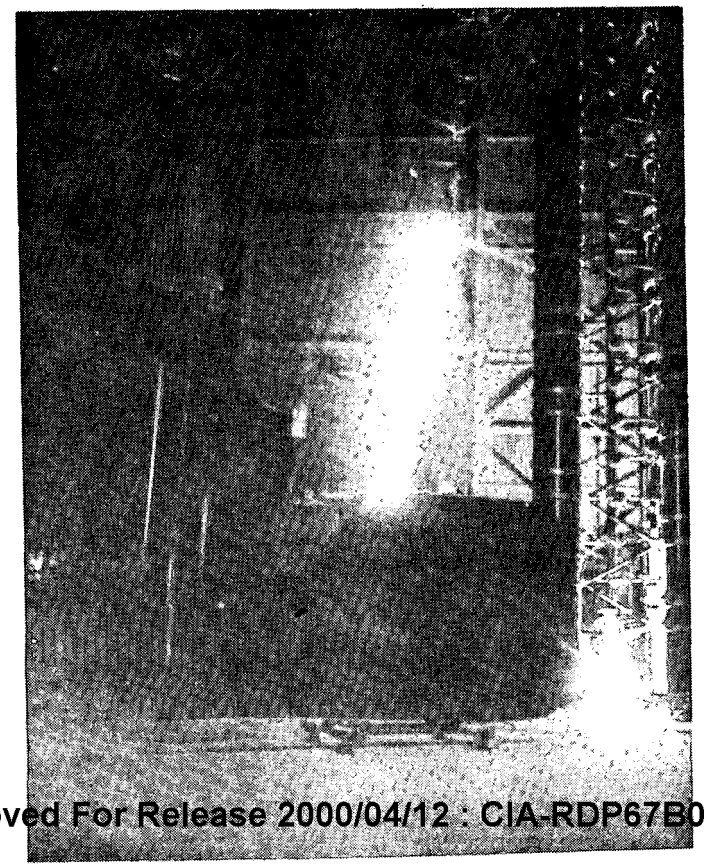

Photo X-3.

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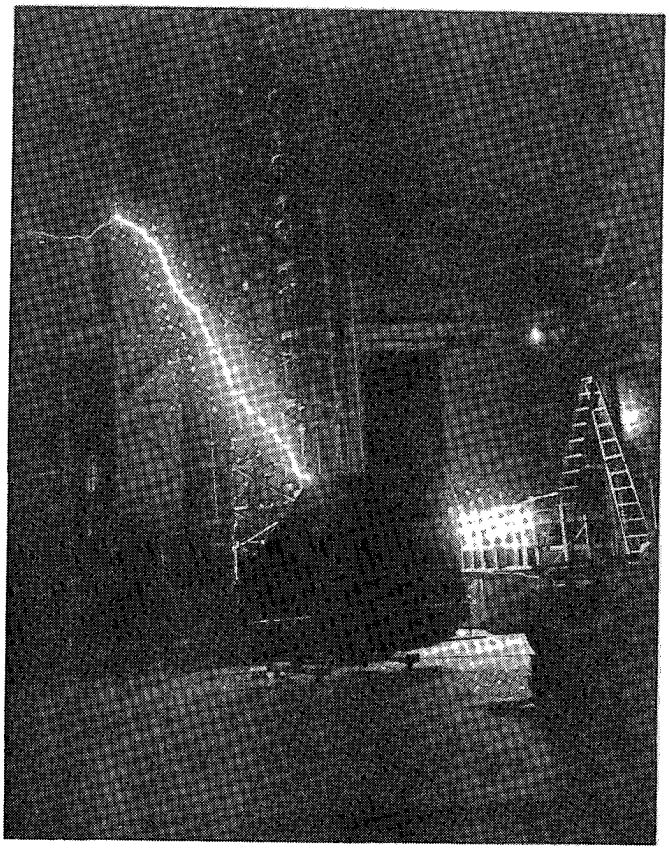

Photo XI-1. Run XI. Aluminum Caps on and short copper lead from Run X retained. Forward electrode location.

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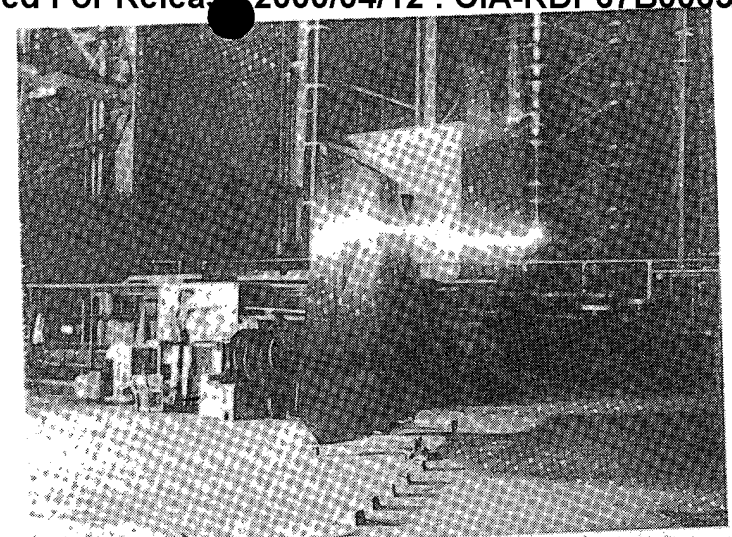

Photo XII-1. Run XII. Forward side discharge. Aluminum caps and copper wire as in Run XI.

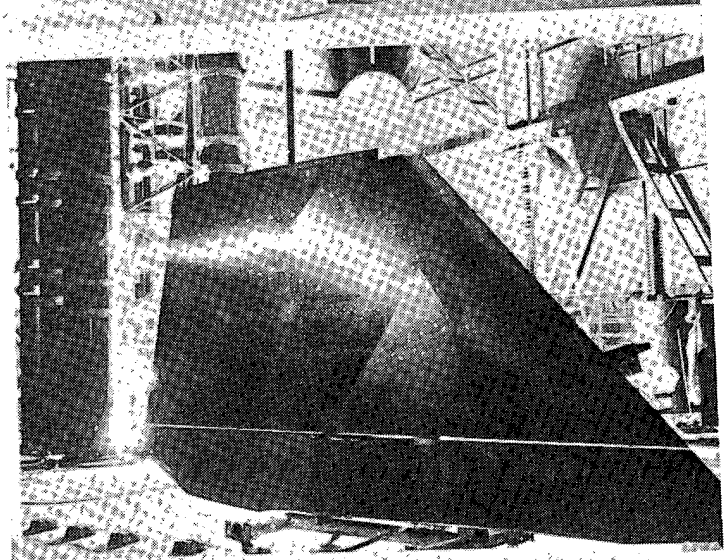

Photo XII-2.

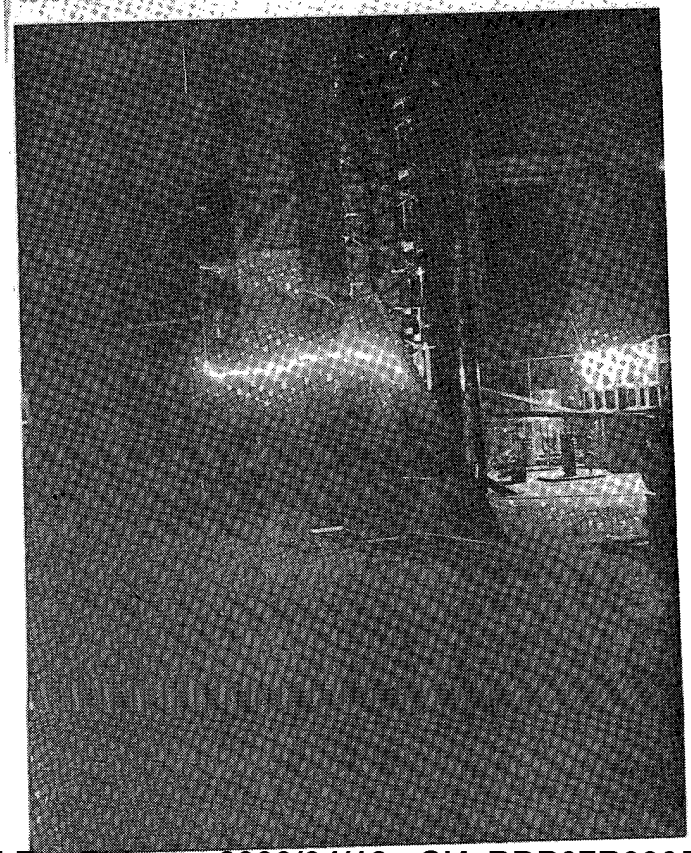

Photo XII-3. Run XII. Note streamer from top of rudder and electrode.

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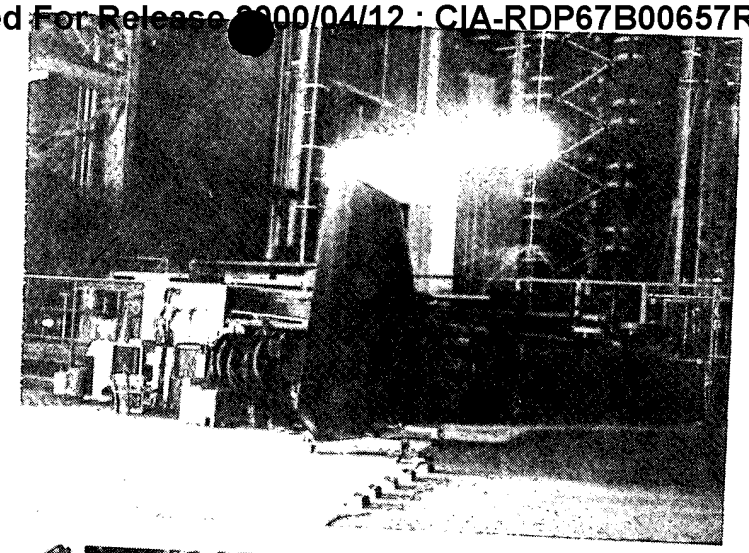

Photo XIII-1. Run XIII. Aft side discharge. Aluminum caps and copper wire as in Run XI.

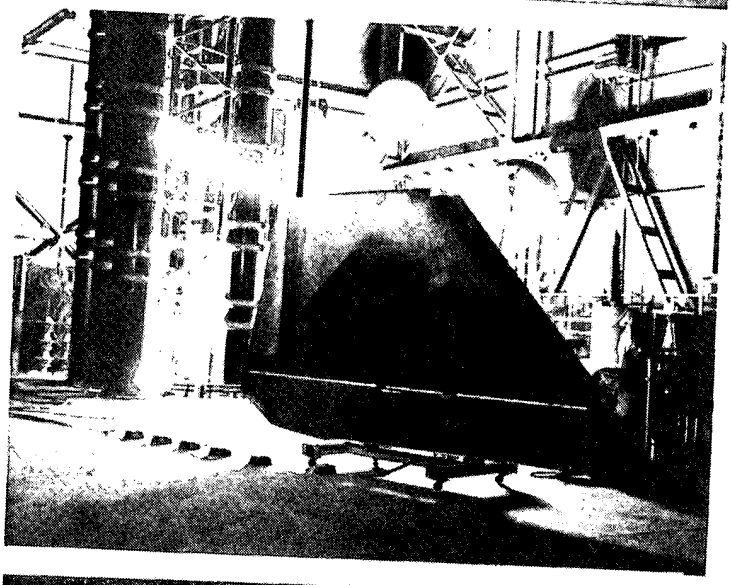

Photo XIII-2.

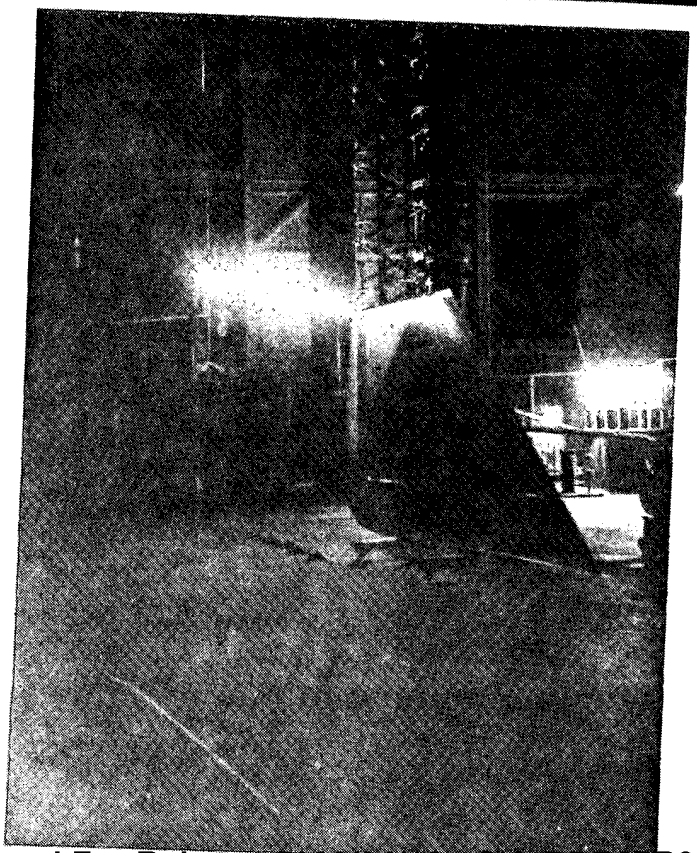

Photo XIII-3.

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Photo XIV-1. Run XIV. Copper dipoles installed.

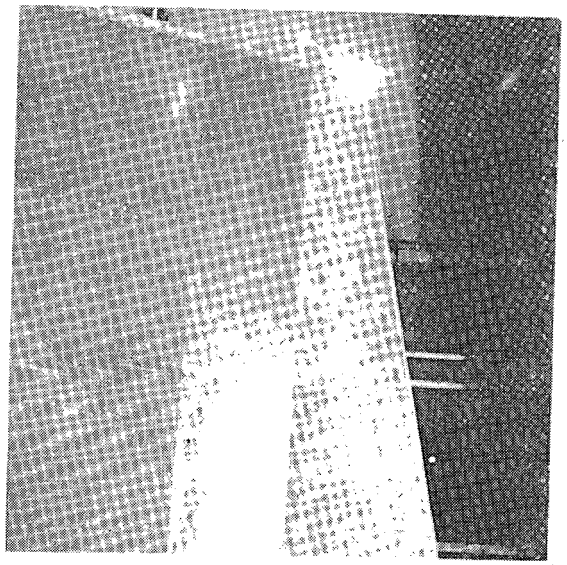

Photo XIV-2. Run XIV. Compare with Run XIII pictures. Aft side discharge.

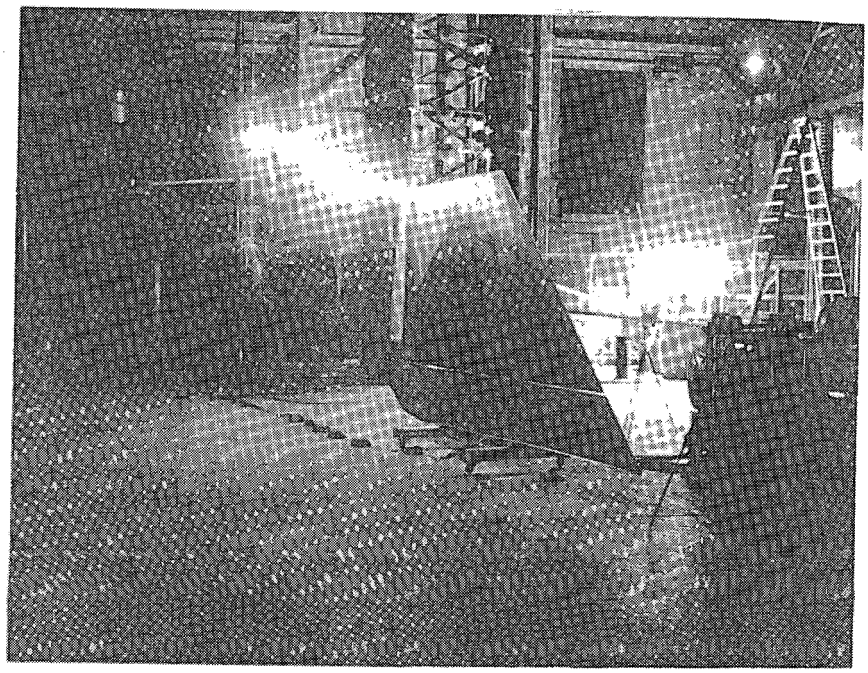

Photo XIV-3.

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